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Research Paper

Creep investigation of GFRP RC Beams - Part A: Literature review and experimental Study

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ABSTRACT

GFRP composite bars are excellent alternative to steel bars for reinforcing concrete structures in severe environments. However, studies on creep phenomenon of GFRP reinforced concrete structures are limited. Creep occurs as a result of long term exposure to high levels of stress that are below the yield strength of the material.

This paper (Part A) presents a literature review and the loading history of six experimental beams reinforced with GFRP and steel bars. The results of this study revealed that Beams reinforced with GFRP are less marked with creep phenomenon. This investigation should guide the civil engineer/designer for a better understanding creep phenomenon in GFRP reinforced concrete members.

1 Introduction

Durability is typically associated with the prediction of the long-term properties of a material in order to assess the time-dependent performance of structures where service lives of 50 years or more are often required. The time-dependent response of a material is generally associated with creep and relaxation. Creep is the time-dependent and permanent deformation of materials when subjected to an externally applied load over an extended period of time [1-3]. Creep is normally an undesired phenomenon that is often the limiting factor in the lifetime of a material. Stress relaxation is the inverse of creep where a material is subject to a constant strain and a reduction in stress occurs over time [4].

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The creep behaviour is characterized by a transfer of matrix stress to the fibre stress and makes the fibre strain increase equal to the composite strain [5]. Creep behaviour of FRP composites depends on fibre orientation, fibre volume fraction, and structure of the material; however, creep of FRP composites is predominantly a result of creep in the polymer matrix [1].

Creep is the time-dependent change in strain due to a constant applied stress. Creep behaviour of a composite is highly dependent on the fibre orientation of the system. The time-dependent response of the composite is most affected when off-axis loading is applied and is less affected when load is applied in the fibre direction [6-7]. The primary or transient state of creep is characterized by a rapidly decreasing creep rate. In secondary creep, the creep strain rate reaches a steady-state value and is followed by the tertiary creep, where a rapid increase in creep strain rate occurs until fracture or rupture of the material [8].

The observed creep behaviour, stress rupture, and stress relaxation of the composite can be attributed to the time-dependent growth of fibre matrix debonds and increasing density of microcracks in the matrix [9]. Consequently, the creep deformation in composites is typically associated with the viscoelastic behaviour of the polymer matrix. The viscoelastic behaviour of polymers is well documented and a number of texts are readily available [10-12].

An understanding of the time-dependent behaviour of FRP composites under synergistic conditions is an important consideration for the design and performance of composites in infrastructure applications. When using GFRP rebars, ACI design guidelines recommend a minimum value amount of GFRP rebar rather than specifying a maximum value [13]. The results of a recent investigation proposed a new parameter design reinforcement ratio [14]. When a concrete element fails, the concrete will be the weak link and will crush in compression. The failure occurs because of concrete fail in compression (over reinforced). The crushing concrete will serve as the warning of failure and there will still be ample reserve tensile capacity in the GFRP reinforcing. Another major difference is that serviceability will be more of a design limitation in GFRP reinforced concrete elements than in steel reinforced members. Due to its lower modulus of elasticity, deflection and crack width will affect the design. Deflection and crack width serviceability requirements will provide additional warning of failure prior to compression failure of the concrete. In many instances, deflection and crack width will control design. Detailed design guidance can be found in the American Concrete Institute publication "Guide for the Design and Construction of Concrete Reinforced with FRP Bars". Design Guidelines for GFRP Reinforced Concrete have been published [15-16]. In most cases, at the level of a structure or component, creep and stress relaxation can be guarded against or reduced significantly by taking advantage of the fact that creep and stress relaxation response is likely to be resin dominated for most practical civil infrastructure applications. Thus appropriate selection and processing of resins and the designed placement of fibres can solve a large part of the challenge. Readers are referred to the excellent reviews for further explanations [16-17]. It has been well established that Aramid and Glass fibres have a higher level of susceptibility to creep rupture at lower stress levels than carbon fibres [19].

There has been one study of the long-term creep behaviour of vinyl and polyesters as a function of cure conditions using flexural creep tests at ambient temperature [20]. The total creep compliance as well as the time exponent decreased systematically with increasing cure condition and time, with creep compliance for room temperature cure for one day that is 250% more than that for a neat vinylester cured for four hours at 93°C. Since concrete beams subjected to a repeated loading will experience an increase in deflections, satisfactory prediction of this time dependent quantity may be important in cases where serviceability criteria govern the design. In addition excessive deflection increase could signal the impending failure. In certain cases there could be change in stress in reinforcement due to creeping of concrete [21-22]. In another important research, reported in [23] showed a characteristic creep behaviour of the material, with a creep deformation. At the end of the test, after 1600 h, the deformation achieved a maximum increase of 15%. The creep recovery was very significant. In the case of beams under typical loading level (33% of Pu), the predicted deflections indicated a 35% increase in creep deflection after 1 year of loading and 100% increase after 50 years. [24]. Another testing set-up for creep in bending of unreinforced and GFRP-reinforced polymer concrete were conducted for composite beams made of polymer concrete unreinforced and reinforced with glass fiber plastic. Bars have been submitted to long-term creep tests in a four point bending set-up at room temperature at load levels of 15%, 30% and 45% of maximum load. These tests demonstrated that unreinforced beams are linear viscoelastic up to 30% of the ultimate load. However the huge increase in the rebar tensile stress represents a stress level of almost 50% of rebar tensile failure load, for an applied load level of 45% of ultimate load. In a sustained load application at this stress level, creep and creep rupture of rebars should be considered in a long term analysis [25]. The static results show similar bending stiffness with similar tensile cracking and similar maximum load. Some scale effects are visible as in four point bending tests the first crack stress level is about 17% higher than in corresponding stress level for three-point bending tests [26]. The effect of different environmental conditions on the creep behaviour of concrete beams reinforced with glass fibre reinforced polymer (GFRP) bars under sustained loads is investigated. This is achieved through testing concrete beams reinforced with GFRP bars and subjected to a stress level of about 20–25% of the ultimate stress of the GFRP bars. The results show that the creep effect due to sustained loads was significant for all environments considered in the study and the highest effect was on beams subjected to wet/dry cycles of sea-water at 40 ± 2 C. [27].

Concrete beams reinforced with GFRP bars were conditioned under the individual or coupled effect of sustained loads and freeze/thaw cycles (100, 200 and 360), and then tested to failure. Creep strain in the GFRP bars are less than 2.0 % of the initial value after 26 weeks (4360 h) of sustain tensile loading. This value was obtained under considerably high sustained stress of 27% of the ultimate tensile strength of the GFRP bars [28].

The impact of composite creep deformation on a structure can be minimized by appropriate selection and processing of resins, and the placement of fibres, with the understanding that creep effects will occur in the matrix [7]. In light of environmental factors and varying load cycles in structures, the time-dependent response of composite materials will ultimately have an impact on the service life of a structure.

Although there is no universal creep–durability solution for all structures, elucidating the influence of the time-dependent behaviour of the composite on the safety of the structural system is the ultimate goal. Understanding the complex interaction of creep, fatigue, moisture, aging, and other factors of all materials (e.g. steel corrosion, concrete cracking, etc.) within the structural system can potentially lead to the development of analytical models to predict the remaining service life of structures

The fibres of Schock Combar are oriented linearly, resulting in the highest possible axial tensile strength. Thus these GFRP bars remain linearly elastic up to failure. When the tensile strength of the material is exceeded, yielding does not occur. However, GFRP shows relatively low tensile and compressive strength perpendicular to the fibres [29-31].

The objectives of this paper (Part A) is to demonstrate from literature review and the loading history of six experimental beams that , beams reinforced with GFRP are less marked with creep phenomenon. This investigation should guide the civil engineer/designer for a better understanding creep phenomenon in GFRP reinforced concrete members.

2 Experimental study

2.1 Beam description

A total of six RC beam specimens of dimensions: 150 mm x 200 mm x 2000 mm, were fabricated with concrete cover of 20 mm. For the tensile reinforcement, two 12 mm diameter were used, and for the compressive reinforcement, two 8 mm diameter. Properties of the GFRP and steel bars used in this study and the details of beam cross-section are shown in table 1, and Figure 1.

Table 1. Properties of the GFRP and steel bars used in this study

Type of bar	Glass	Steel
Nominal diameter (mm)	12 and 8	12 and 8
Tensile Modulus of Elasticity (GPa)	60 ±1.9	200 ± 7
Ultimate Tensile Strength (MPa)	738 ± 22	400 ± 11
Coefficient of thermal expansion (mm/mm/°C)	2.2 x 10^{-5} (radial)	2.2 x 10^{-5}
Density	2.2	7.85

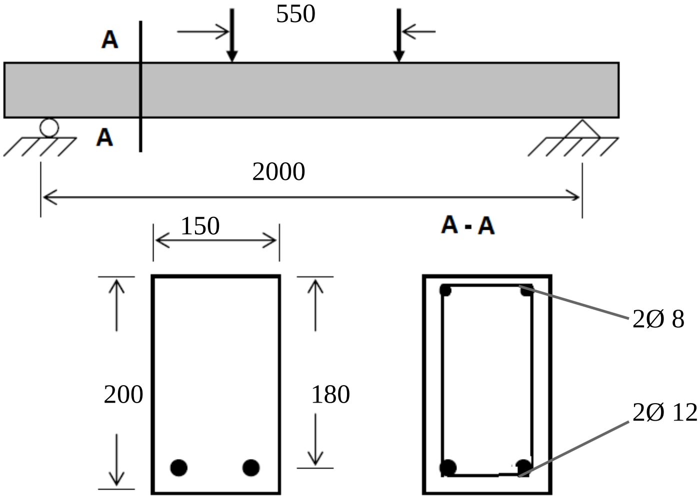

Fig. 1 – GFRP bars reinforcement and Beam Cross section

Three of the beams, were reinforced with GFRP bars and three with steel bars. The average yield strength was 1000MPa and 400MPa, respectively. The modulus of elasticity of the tensile reinforcement bars were 60GPa and 200GPa, respectively.

All beams were provided with 6 mm diameter mild stirrup and were designed to fail in flexure. 30MPa Concrete grade was used in the manufacturing of these beams using Ordinary Portland cement and crushed aggregates with maximum size of 12 mm. Table 2

Table 2. Concrete composition and characteristics

Cement I 42.5 (kg/m^3)	Water (kg/m^3)	Sand (kg/m^3)	Aggregate 12/20 (kg/m^3)	Aggregate 4/12 (kg/m^3)	Slump (mm)	Compressive Strength (MPa)
400	204	857	691	296	90± 2	30±3

2.2 Set-up and instrumentation Test:

The beams were subjected to sustained loads for a period of 300 days to compare under sustained loading the deflection of the beams reinforced with GFRP and steel bars in ambient laboratory condition. To simulate the sustained loading, beams were placed at one-four points us shown in Figure 2.

Fig. 2 – Sustained loading

The mid-span deflection was monitored by a Linear Variable Displacement Transducer (LVDT) with accuracy equal to 0.001mm, placed underneath the centre of the beam (Fig 3). All the beams were tested simply supported at the age of 28 days under four-point loading.

Fig. 3 – Beam test instrumentation

Pure bending is a condition of stress where a bending moment is applied to a beam without the simultaneous application of axial, shear, or tensional forces. Pure bending is the flexure (bending) of a beam under a constant bending moment (M) therefore pure bending only occurs when the shear force (V) is equal to zero, since dM/dx= V

The schematic diagram of the testing arrangement of the beam is shown in Figure 4.

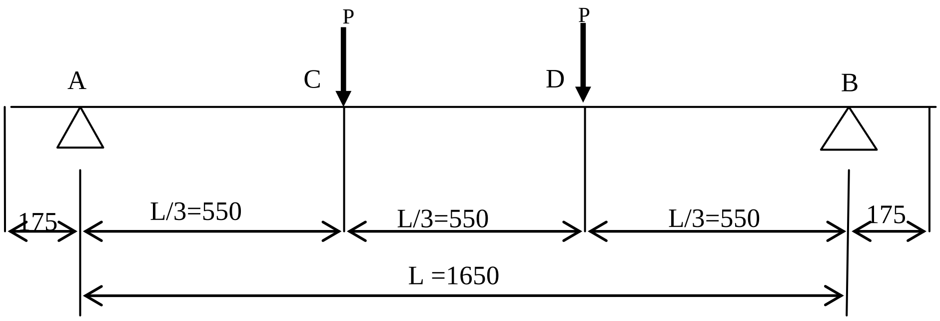

Fig. 4 – Schematic diagram of testing arrangement

2.3 Presentation and discussion of test results

2.3.1 Proportionality load/deflection

We took a series of flexions measurement for all six beams charged reinforced by steel and GFRP bars. We can notice for values weak of loading a linear variation load/deflection.

The groups of dots as well as the linear behavior are represented by the figure 5.

2.3.2 Deflection variation in time

A constant load has been maintained for 400 days, with regular deflection measurements value. It can be noted during the loading period, that the deflection of the two steel and GFRP reinforced beams increases slightly towards a tendency to stabilize them in time (Fig. 6). It can be concluded that GFRP reinforced beams are less marked by the creep phenomenon, since under a constant loading the GFRP reinforced beams present a deflection variation less marked than those reinforced by steel.

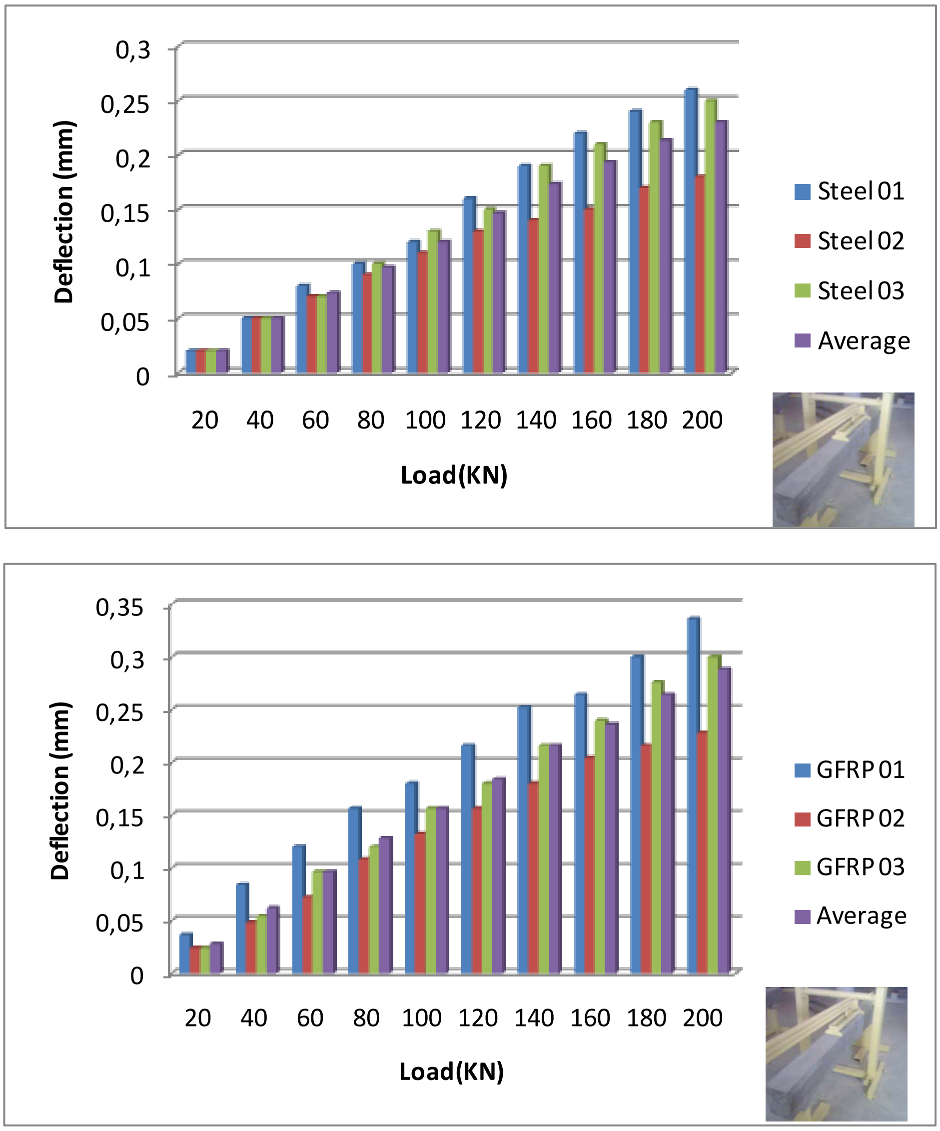

Fig. 5 – Proportionality Load/deflection

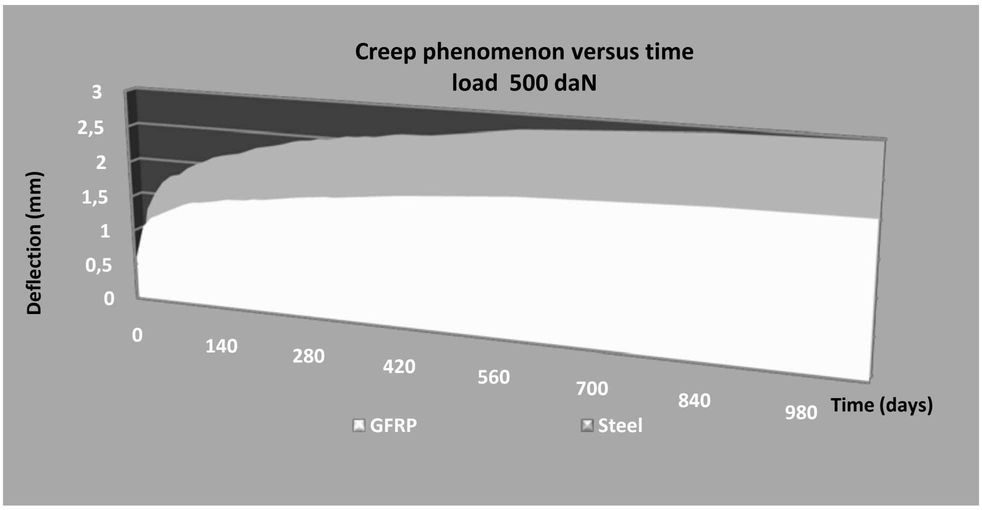

Fig. 6 – Creep phenomenon versus time

3 Conclusion

This paper present a study about the creep behaviour of GFRP pultruded profiles. A brief review was first presented concerning the main previous experimental about the creep response of GFRP materials, most of which subjected to flexural loads. From the literature review and the experimental investigation carried out, the following conclusions can be drawn:

- Creep is proportional to the modulus of concrete and the applied stress (creep linear);
- Under a constant loading the GFRP reinforced beams present a deflection variation less marked than those reinforced by steel;
- Beams reinforced with GFRP are less marked with creep phenomenon that those reinforced with Steel bars;
- Understanding the complex interaction of creep and other factors of all materials should guide the civil engineer for a better/design;
- The deflection of the two steel and GFRP reinforced beams increases slightly towards a tendency to stabilize them in time.

The flexural creep response of GFRP pultruded beams studied in this work have also been investigated by means of analytical investigations, in which the accuracy of existing formulae was assessed. The results of these analytical investigations, as well as their comparison with the experimental strain and deflection measurements, are reported in a companion paper (Part B).

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